ON POSSIBILITY OF HIGH FREQUENCY ELECTRON BEAM SCANNING WITH APPLICATION OF FOCUSING SYSTEM FOR X-RAY GENERATION

T.V. Bondarenko
OOO "Siemens", Moscow, Russia
E-mail: taras.bondarenko@siemens.com

The article describes the electron beam scanning system in combination with electromagnetic focusing system. These systems find their application in different vacuum tube devices that provide the generation of X-ray radiation. Similar systems can be utilized in such fields as medicine, industry and defectoscopy. Electron tube system can be based on thermal or field emission cathodes. Scanning system is built up on two pair of electrical deflecting dipoles. The scanning can also be based on magnetic deflecting system. Beam focusing is achieved by the geometrical features of electrodes structure and electron lenses. Magnetic focusing can also be used for transversal focusing of the beam. The article describes the schemes of the unit with electron beam scanning and different methods of realization. Beam dynamics investigation in electromagnetic fields of the unit is considered.

PACS: 41.85.-p, 41.75.-i, 07.77.Ka

INTRODUCTION

Electron guns are widely used in different applications fields nowadays. One of them is vacuum tube devices that incorporate diode or triode system for X-ray generation better known as X-ray tubes. X-ray tubes are used in a lot of applications such as defectoscopy, industry, medical, veterinary, crystallography and many others. In most of the tubes stationary electron beams with pretty large focal spot sizes are used. This allows using the simplified conventional unit geometry.

Despite this fact for some applications smaller spot sizes are required to acquire high spatial resolution of the emitted X-ray radiation in order to provide the high resolution images [1]. This requirement can be satisfied by applying additional focusing electrode to the X-ray tube scheme.

Another idea lies in the possibility to perform electron beam scanning along the anode surface. This solution can be exploited to enhance the anode loading rate and let the anode to hold higher beam powers. This correspondingly will enhance the X-ray radiation intensity.

These two ideas can be accomplished by the X-ray tube design that is schematically represented in this paper.

1. X-RAY TUBE DESIGN

The X-ray tube design can be based on various types of cathodes such as thermal sources (filaments, dispenser cathodes or lanthanum hexaboride cathodes) or field emission cathodes (pin or CNT cathodes). The difference between the designs of the X-ray tubes based on such cathodes lies in the cathode electrode scheme modification. All other components of the X-ray tube are saved untouched.

For example in this paper the dispenser cathode X-ray tube was considered to overview the generic scheme. The X-ray tube design is presented on the Fig. 1. On the figure: 1 – dispenser cathode; 2 – cathode cup (Wehnelt electrode); 3 – focusing electrode; 4 – anode; 5 – deflecting electrodes; 6 – dielectric spacers and holders.

Cathode is formed on the round dispenser cathode with the spherical cut-off for forming of the initial beam convergence. The Wehnelt electrode is made on the cylindrical design with the chamfering of the inner edge. Focusing electrode is designed with the overhanging part towards the cathode area that is very similar to the anode in Pierce type gun conventional design [2]. The difference consists in the fact that the focusing electrode is made with constant width all over the geometry and beam have no need to travel through the metal channel with the lack of focusing E field. The chamfer of the focusing electrode edge close to cathode is made to eliminate the collision of the electron beam particles that travel from the side farts of the cathode.

Two pairs of deflecting electrodes are placed after the focusing electrode to provide the electron beam scanning along the anode surface. Scanning motion can be also provided by the magnets placed in much the same way as electrodes but in current consideration only electrical deflecting system is considered due to low dimensions of such system. The electrodes are fixed on the dielectric chucks for high electrical isolation from each other and other adjacent metal elements. Each pair provides transverse deflection of the beam along one of the axes.

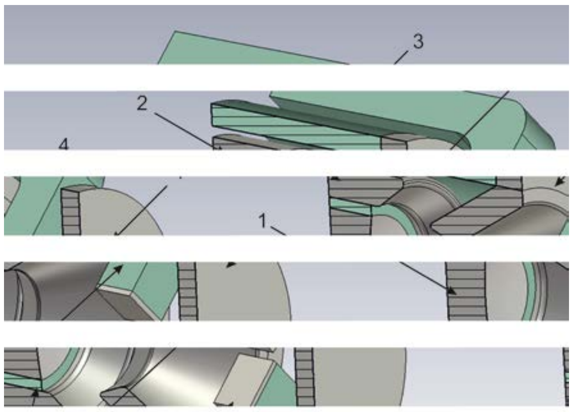

Fig. 1. Generalized X-ray tube design

The chamfer widths and angles of the focusing electrode and Wehnelt electrode are the main geometrical parameters that allow optimization of the electron beam focal plane and size. The electrical potentials of the Wehnelt electrode and the focusing electrode are the two electrical parameters varying the electron beam focal spot parameters.

2. MODELING

First step of the modeling was to acquire the maximum stationary beam focusing in the predefined sizes of the X-ray tube geometry. The desired electron beam energy was taken 150 keV, maximal of the working parameter values used in the applications listed above. The cathode radius is 5 mm that allows acquisition of the emitting currents up to ampere level [3]. Cathode-anode distance is 30 mm that allows the unit to operate without discharge threat. The potential set on the scanning electrodes must be equal to the potential of the free space in their location position that is approximately equal to the mean value of potential between the focusing electrode and the anode. More precisely it is defined from the potential plot of the calculated model.

The model was calculated for several values of the beam emitted current (from 10 mA to 1 A) to estimate the possibility of beam focusing. The results are depicted on the Fig. 2. The potential distribution and beam trajectories in the model with optimized geometrical dimensions and parameters are presented on the Fig. 3. Beam size can be reduced from 5 up to 15 times relative to cathode beam spot size.

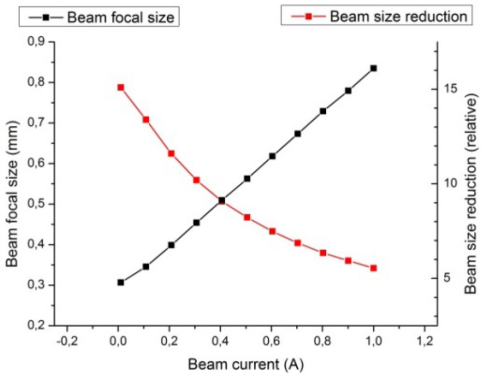

Fig. 2. Beam focal spot size vs. current value

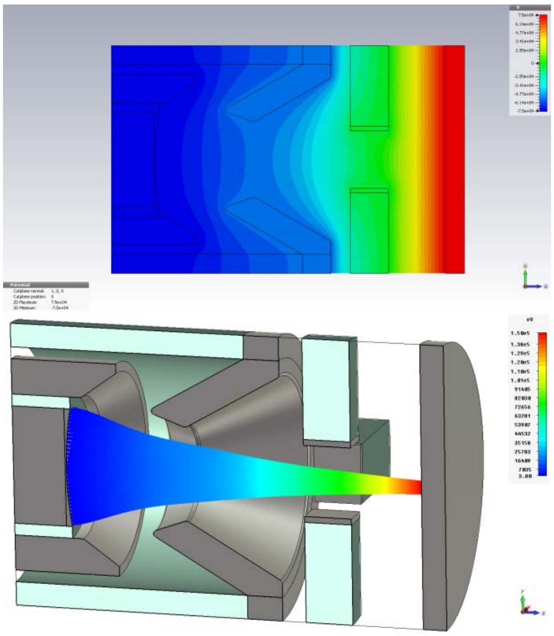

Fig. 3. Potential distribution and electron beam trajectories in the unit model without deflection

The next step was to achieve the beam scanning with the deflecting plates. Additional deflecting potential was added to and subtracted from the reference voltage on the opposing electrodes of the pair. The reference potential on the scanning plates was set to 10 kV. The values of the beam deflection relative to the axis and deflection from the axis relative to the deviation of the electrons transversal distribution in the beam vs. the deflecting voltage are depicted on the Fig. 4. This case was considered with 400 mA beam current that corresponds to approximately 0.5 mm focal beam spot size.

The focal spot size of the beam is slightly increased while deflecting it along the axis because of the enhanced path that beam travels until it crashes the anode. Yet the beam size is reduced along the deflection axis that can be seen on the beam profile picture and phase space views shown on the Figs. 5-7. According to this along with beam deflection the focusing potential must also be tuned to obtain the beam focal plane right on the anode surface otherwise the beam will grow in the direction oppose to the deflection plane.

The results show that electron beam can be scanned by electrostatic system with medium-range values of deflecting potential set to the electrodes over the surface on anode exceeding the beam focal spot surface approximately 300 times that will give possibilities to reduce the X-ray tube anode loading with the electron beam and increase the possible X-ray power levels.

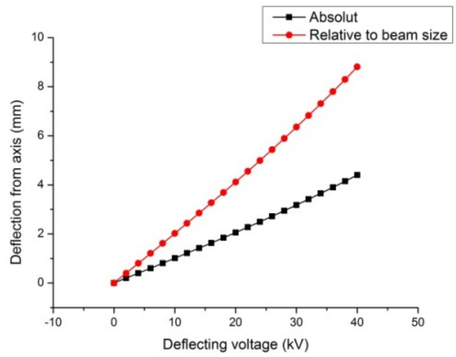

Fig. 4. Beam deflection vs. the deflecting voltage

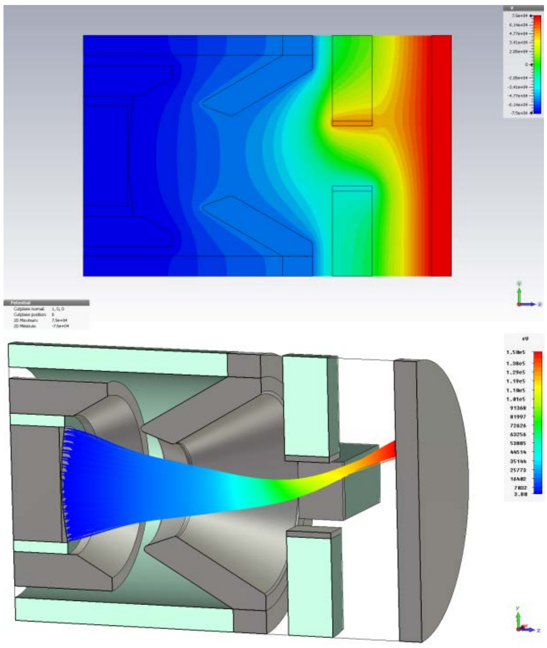

Fig. 5. Potential distribution and electron beam trajectories in the unit model with deflection

ISSN 1562-6016. ВАНТ. 2014. №3(91)

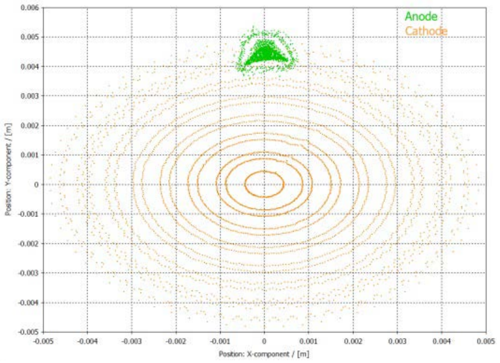

Fig. 6. Beam profiles on the cathode and anode surfaces

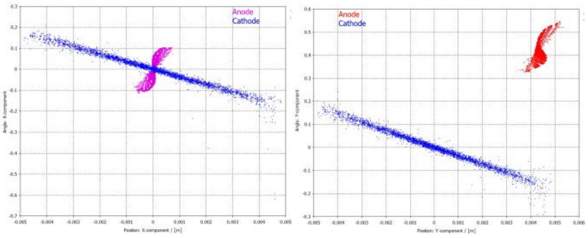

Fig. 7. Phase space view of the electron beam on cathode and anode

CONCLUSIONS

X-ray tube design for acquiring high values of beam focusing was schematically modeled and calculated. Results shows that electron beam size can be reduced up to 15 times relative to cathode dimensions and electron scanning can cover the anode surface 300 times larger than the focal spot size. These results can be implemented in X-ray tubes that require high focusing or beam scanning of the electron beam along the anode surface.

REFERENCES

1. G.T. Barnes, B.J. Conway, A.G. Haus, et al. Equipment requirements and quality control for mammography // *AAPM report*. 1990, №29, 72 p.
2. Stanley Humphries. *Charged Particle Beams*. New York: John Wiley & Sons, 1990.
3. HeatWave Labs, Inc. Standard Series Barium Tungsten Dispenser Cathodes, http://www.cathode.com/

Article received 13.11.2013

ВОЗМОЖНОСТИ ВЫСОКОЧАСТОТНОГО СКАНИРОВАНИЯ ЭЛЕКТРОННОГО ПУЧКА С СИСТЕМОЙ ФОКУСИРОВКИ ДЛЯ ГЕНЕРАЦИИ РЕНТГЕНОВСКОГО ИЗЛУЧЕНИЯ

Т.В. Бондаренко

Описывается система сканирования электронного пучка в комбинации с системой электромагнитной фокусировки. Такая система находит применение в различных электровакуумных приборах, осуществляющих генерацию рентгеновского излучения. Подобные приборы могут быть использованы в таких областях, как медицина, индустрия и дефектоскопия. Электровакуумная система может быть основана на термо- или автоэмиссионном катоде. Система сканирования выполняется на основе двух пар электрических отклоняющих диполей. Также сканирование может быть осуществлено за счет магнитной системы. Фокусировка пучка выполняется за счет геометрических особенностей строения электродов и электронных линз и на магнитной системе фокусировки для обеспечения поперечного сжатия пучка до субмиллиметровых размеров. Приводятся схемы установки со сканированием электронного пучка и различные методы их реализации. Рассматривается динамика пучка электронов в электромагнитных полях системы.

МОЖЛИВОСТІ ВИСОКОЧАСТОТНОГО СКАНУВАННЯ ЕЛЕКТРОННОГО ПУЧКА З СИСТЕМОЮ ФОКУСУВАННЯ ДЛЯ ГЕНЕРАЦІЇ РЕНТГЕНІВСЬКОГО ВИПРОМІНЮВАННЯ

Т.В. Бондаренко

Описується система сканування електронного пучка в комбінації з системою електромагнітного фокусування. Така система знаходить застосування в різних електровакуумних приладах, що здійснюють генерацію рентгенівського випромінювання. Подібні прилади можуть бути використані в таких областях, як медицина, індустрія і дефектоскопія. Електровакуумна система може бути заснована на термо- або автоемісійному катоді. Система сканування виконується на основі двох пар електричних диполів, що відхиляють. Також сканування може бути здійснене за рахунок магнітної системи. Фокусування пучка виконується за рахунок геометричних особливостей будови електродів і електронних лінз і на магнітній системі фокусування для забезпечення поперечного стискнення пучка до субміліметрових розмірів. Наводяться схеми установки із скануванням електронного пучка і різні методи їх реалізації. Розглядається динаміка пучка електронів в електромагнітних полях системи.